

## METHOD OF MANUFACTURING AN OPTICAL FIBER

This is a continuation-in-part application of Patent Application Serial No. 09/351,951 filed July 12, 1999.

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### BACKGROUND OF THE INVENTION

#### Field of the Invention

The present invention relates to a method of manufacturing an optical fiber.

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#### Description of the Related Art

Optical fibers using silica glass fibers have been utilized for transmitting ultraviolet rays (hereinafter referred to as UV) (especially excimer laser beam), for example, in a photomask for excimer laser lithography, in a light guide for transmitting UV used to irradiate UV-hardening resin, and in the fields of microfabrication, medical treatment and the like.

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When an optical fiber is used for transmitting UV, for example, to irradiate a UV-hardening resin, it is required to transmit UV with a shorter wavelength and higher power, so that the hardening time of the resin can be reduced. The peculiarity of short wavelength and high power of the UV must therefor be fully available.

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However, when UV is transmitted through silica glass, a problem occurs that structural defects are formed in the silica glass, which decrease the transmittance. The decrease of transmittance of silica glass becomes more remarkable, as the wavelength of UV becomes shorter and its light power becomes higher. Therefore, when an excimer laser is used as a light source, the transmittance of silica glass becomes worse especially with KrF excimer laser (wavelength : 248nm) to F<sub>2</sub> excimer laser (wavelength : 157nm) including ArF excimer laser (wavelength : 193nm). The transmittance becomes worse when a laser of higher light power (one of various excimer lasers like KrF, ArF and F<sub>2</sub> ) is used as opposed to when a lamp of lower light power (a halogen lamp, a deuterium discharge lamp and the like) is used as a light source.

In order to reduce the decrease of transmittance of silica glass due to UV irradiation, or to improve resistance of silica glass to UV, a technique of increasing the hydroxyl group content of silica glass has been proposed in the publication of Japanese Unexamined Patent Application Hei 4-342427, the publication of Japanese Unexamined Patent Application Hei 4-342436, etc. However, when the hydroxyl group content is increased, the wavelength of UV absorption edge becomes

longer, with a result that UV with short wavelength (especially, vacuum ultraviolet zone ) cannot be transmitted.

5 The solution to this problem was provided by a method (disclosed in co-pending U.S. Patent Application Serial No. 09/351,951) in which multiple structural defects are purposefully caused in silica glass by irradiating silica glass with UV, and in which the structural defects are removed by performing heat  
10 treatment simultaneously with or after the UV irradiation.

In applying the method disclosed in the co-pending U.S. Patent Application Serial No. 09/351,951 to a silica glass fiber, there occurred the following problems.

15 When UV with a high power is repeatedly irradiated through the end surface of a fiber to cause structural defects, deterioration occurs only at the irradiated end, and UV does not reach the other end. Therefore, aside from a short fiber, it is impossible to process a long fiber  
20 along its entire length. Also cutting a long fiber into a plurality of short fibers (about 1m, for example) and processing these fibers one by one leads to an increase of costs, and is not appropriate for a long fiber.

25 On the contrary, when UV with a lower power is used for irradiating, a relatively long fiber can be

processed, but the lower power requires a substantially long processing time and is thus unsuitable for mass production.

5 An alternative way of applying UV irradiation to an optical fiber laterally, i.e. from the side of the optical fiber, leads to other problems that an insulation coating (an outer protective coating) made of synthetic resin will be melted due to the heat by UV irradiation, and that a metal coating will prevent the UV from passing  
10 therethrough.

#### SUMMARY OF THE INVENTION

15 It is an object of the invention to provide a method of manufacturing an optical fiber using silica glass whose properties have been changed by UV irradiation and heat treatment, the method facilitating efficient mass production of long optical fibers.

20 To attain these and other objects, in the first aspect of the present invention, there is proposed a method of manufacturing an optical fiber, wherein multiple structural defects are purposefully caused in a silica glass fiber spun out of a base material of silica glass by irradiating the fiber with UV, and wherein UV resistance of the silica glass fiber is improved by removing the

structural defects using heat or the residual heat from the fiber spinning process.

5 In the second aspect of the present invention, there is proposed the method of manufacturing an optical fiber in the first aspect of the present invention, wherein the heating to remove the structural defects is performed before applying an insulation coating.

10 In the third aspect of the present invention, there is proposed the method of manufacturing an optical fiber in the first aspect of the present invention, wherein the heating to remove the structural defects is performed after applying an insulation coating,

#### BRIEF DESCRIPTION OF THE DRAWINGS

15 The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1A is a diagrammatic view of an apparatus for carrying out the method of the present invention; and

20 Fig. 1B is a representation of a portion of fiber illustrating two stages of treatment.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A method of manufacturing an optical fiber according to the present invention is embodied, for example, by the system shown in FIGS. 1A and 1B.

5 Referring to FIG. 1A, a base material of silica glass 2 is heated in a spinning furnace 4, and spinning is performed by drawing a silica glass fiber 6 from the point of the spinning furnace 4. In a UV irradiation zone 8, the silica glass fiber 6 which has been spun is irradiated with UV from its side, with a result that multiple  
10 structural defects are caused in the silica glass fiber 6.

These structural defects are removed by heat treatment, and the average bond angle of Si-O-Si network in the silica glass is increased compared with that before the heat treatment. As a result, structural relaxation  
15 proceeds to give structurally stable glass, and defects due to further UV irradiation are prevented from being formed. A silica glass fiber 6 having greater resistance to UV irradiation caused defects, compared with a silica glass fiber without UV irradiation and heat treatment  
20 performed, is thus obtained. Furthermore, increasing UV resistance according to this method results in preventing deterioration of transmittance of silica glass due to radioactive irradiation, that is, resistance to radiation can be improved.

When the residual heat from heating for fiber spinning is enough for the above described heat treatment, it is unnecessary to further heat the silica glass fiber 6. When the residual heat is not enough, the silica glass fiber 6 may be heated within a heating zone 10 provided subsequent to the UV irradiation zone 8, as shown in Fig. 1B.

When the silica glass fiber 6 irradiated with UV (and also heat treated in the example shown in Fig. 1B) passes through a fiber diameter measuring device 12, the fiber diameter is measured, and a fiber diameter controller 14 controls the rotating speed (spinning speed) of a capstan 16 based on the measured values. After passing through the fiber diameter measuring device 12, an insulation coating is applied to the fiber 6 by a coating device 20 to form a completed optical fiber, which is then wound up by a winder 22. The fiber diameter measuring device 12, the coating device 20, the fiber diameter controller 14, the capstan 16 and the winder 22 are similar to known ones, respectively, both in structure and in operation.

With respect to UV irradiation and heat treatment applied to a silica glass fiber 6, the following conditions and features are to be noted.

5 The wavelength of the UV to be irradiated is appropriately within 50nm-300nm, preferably within 130nm-250nm, and further preferably within 150nm-200nm. When the wavelength is above these ranges, the UV resistance and radiation resistance improving effects tend to decrease, and when the wavelength is below the range, the effectiveness of the UV resistance and radiation resistance improvement is limited.

10 The intensity of the UV to be irradiated is appropriately within 0.01mJ/cm<sup>2</sup>-1000mJ/cm<sup>2</sup>, preferably within 1mJ/cm<sup>2</sup>-500mJ/cm<sup>2</sup>, and further preferably within 1mJ/cm<sup>2</sup>-30mJ/cm<sup>2</sup>. When the intensity is above these ranges, the deterioration of silica glass tend to increase, and when the intensity is below these ranges, the effectiveness of UV resistance and radiation resistance improvement tends to decrease.

15 As a UV source, which is not limited specifically, an ArF excimer laser, a KrF excimer laser, an excimer lamp, a deuterium lamp, and the like can be employed, for example.

20 UV irradiation must be continued long enough for structural defects to be caused (this can be confirmed by a decrease of the UV transmittance). In other words, it is necessary to continue UV irradiation until the decrease of the UV transmittance reaches a desired limit.

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In the present invention, however, in which the silica glass fiber 6 is irradiated with UV while being spun, it is difficult to confirm during irradiation (spinning) whether the UV transmittance is decreased.

5 Therefore, it is preferable to previously determine an appropriate condition of irradiation based on an experiment or the like, considering the UV intensity, the spinning speed, and the material and the size of the silica glass fiber 6, then perform UV irradiation in  
10 accordance with the condition.

The temperature of the heat treatment is approximately from 100°C to 1600°C, preferably from 200°C to 1400°C, and further preferably from 300°C to 1300°C. When the temperature is outside these ranges,  
15 the UV resistance and radiation resistance improving effects tend to decrease. Accordingly, it is to be determined whether to provide the above mentioned heating zone depending on whether the temperature of the silica glass fiber 6 after enough UV radiation is  
20 performed, i.e. the temperature of the spun fiber due to the residual heat, is within these ranges.

The variation of bond angle of Si-O-Si network due to heat treatment (by the residual heat or further heating) can be confirmed by analyzing the peak point of  
25 infrared absorption around  $2260\text{cm}^{-1}$  in the infrared

absorption measurement. Specifically, as the structural relaxation of the silica glass proceeds ( i.e. as the resistance to UV caused defects increases ), the peak point of infrared absorption around  $2260\text{cm}^{-1}$  in the infrared absorption measurement is shifted to a higher frequency side (shorter wavelength side) within the range from about  $2255\text{cm}^{-1}$  to about  $2275\text{cm}^{-1}$ .

In the present invention, however, in which the silica glass fiber 6 is heat treated while being spun, it is difficult to confirm the variation of bond angle of Si-O-Si network by analyzing the peak point of infrared absorption in real time.

Therefore, when the heating zone is provided, it is required to determine the temperature of the heat source, the whole length of the heating zone, and the like considering the spinning speed of the silica glass fiber 6. It is preferable to previously determine an appropriate condition of heating based on an experiment or the like in the same way as in the case of UV irradiation, and perform heating in accordance with these conditions.

A known silica glass optical fiber has a three-layer structure which consists of a core, a clad, and an insulation coating in order from its center. The clad is made of fluorine-added silica glass, and the core is made of genuine silica glass, OH-group-added silica glass, or

silica glass to which fluorine of a density lower than that in the clad is added. The present invention can be applied to an optical fiber using silica glass of other kinds as well as a known optical fiber such as the above.

5 Furthermore, there is no particular limitation to the material of the coating, although it is preferable to perform heating to remove structural defects before applying a insulation coating having low heat resistance (e.g. a resin coating) because relatively high  
10 temperatures are required for heat treatment (cf. FIG. 1B).

In contrast, an insulation coating of a material having high heat resistance (e.g. metals such as aluminum and gold) can well withstand high  
15 temperatures for heat treatment, and therefore heat treatment may be performed after applying the coating by a heating furnace 100, for example, arranged at the position indicated by dotted lines in FIG. 1A. Heat treatment can, of course, be performed before applying  
20 the coating. In brief, an insulation coating having good heat resistance provides the option of arranging the location of heat treatment.

Heating after UV irradiation is preferably but not restrictively by irradiation using an electric furnace, an

infrared lamp and an infrared laser. At least, a non-contact heating method of radiation is desirable.

Also, since any metal coating is a good absorber of near infrared radiation, near infrared radiation should be used in the case of heating after applying a metal coating.

As described above, according to the manufacturing method of an optical fiber in the present invention, the UV resistance of the silica glass fiber 6 constituting the optical fiber is improved by irradiating UV to the silica glass fiber 6 to cause structural defects therein during spinning out of the base material and removing the structural defects by the residual heat from the fiber spinning process or further provided heat, thereby increasing the average bond angle of Si-O-Si network in the silica glass fiber 6 compared with that before heat treatment.

In the present method, UV is irradiated laterally, or from the side of the silica glass fiber 6, there is no limitation to the length of the silica glass fiber 6. This facilitates manufacturing of a long optical fiber using silica glass fiber 6 having high UV resistance.

Furthermore, what is necessary is just to provide a UV irradiation zone in the conventional manufacturing process of an optical fiber, and provide a separate

heating zone only when heat treatment by the residual  
heat is not sufficient. Accordingly, existing equipment  
for manufacturing optical fibers can be used as it is and  
thus a new investment in equipment (UV irradiation  
5 equipment and heating equipment, if appropriate) can be  
minimized.

It is to be understood that the present invention is  
not limited to the aforementioned embodiment but can be  
embodied in various ways without departing from the  
10 scope of the invention.